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Distributed Exercise Management: the SmartFED approach

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Summary

Distributed simulation requires a novel approach to exercise management. With the introduction of (geographically) distributed simulations, exercise management consists of managing a multitude of simulators in a common scenario. This imposes new challenges with respect to managing the distributed responsibilities of the simulation. NLR's exercise management tool SmartFED (Scenario Manager for Real-Time Federation Directing) is designed to meet these new challenges. This paper provides insight into SmartFED's concepts and practical experiences in the field of distributed real-time (training) simulations.

Contents

(18 pages in total)

1 Introduction

There is a growing interest in geographically distributed training/exercising using distributed simulation. Recently, applications have been published in the military [1], space [2] and civil aerospace [3] domain. Among the reported advantages are the (new) possibility to perform team training, the possibility to include real entities in the simulation, and cost reduction by saving on travel and subsistence.

In DOD's High Level Architecture (HLA) parlance simulators are called federates and a collection of federates in a joined simulation is referred to as a federation. This terminology will be used throughout this paper.

To fully exploit the advantages of distributed simulation exercises three major elements are required:
1. A standardised intercommunication mechanism.
2. A standardised process for federation development and execution.
3. Exercise management.

A novel approach towards automated distributed exercise management is researched by NLR. This has led to the product Scenario MAnager for Real-Time FEderation Directing (SmartFED; see also [4], [5]). The SmartFED tool-suite provides a generic reusable solution to support exercise management of distributed simulations. SmartFED employs HLA as intercommunication mechanism. The applicable steps in the standard Federation Development and Execution Process (FEDEP) process are also supported by SmartFED. SmartFED thus provides the three elements of distributed simulation exercises mentioned above.

The remainder of this paper is organised as follows. In Section 2 distributed real-time simulation and the use of SmartFED in a typical aerospace application is described briefly. Section 3 presents the concepts of exercise management. SmartFED supported distributed exercise management is detailed in Section 4. At present the SmartFED tool-suite consists of three distinct tools: a federation manager tool, a federation monitor tool and a scenario definition and execution manager tool. These three tools are described in more detail in sections 5, 6 and 7. Section 8 elaborates on how SmartFED supports the FEDEP process. Finally, concluding remarks and items for future work are presented in Section 9.

2 Distributed Real-Time Simulation

An artist's impression of a SmartFED application pursued within NLR is given in Figure 1. The application deals with a total solution concept in the area of Air-Traffic Management (ATM)-gate-to-gate. Individual players, e.g. aircraft, airport, and ATM, are supported by dedicated facilities at NLR.

Figure 1: SmartFED in an ATM gate-to-gate federation concept.

To aid simulated entities to interact in the virtual world, in a similar fashion as the real players, proper exercise management is required. For this, SmartFED has been developed. To fully exploit the advantages of distributed simulation exercises three fundamental cornerstones can be identified:

1. A standardised intercommunication mechanism. This has been addressed, first with DIS (Distributed Interactive Simulation) from which evolved HLA (High Level Architecture)

[6]. At present SmartFED is based on HLA. In HLA parlance, simulation entities are called federates that collaborate in a federation to achieve the distributed simulation.

2. A standardised process for federation development and execution. Besides intercommunication standardisation, HLA also brought the FEDEP process [7] to address this aspect.
3. Exercise management. There is no standardisation yet on this aspect, though HLA offers some useful handholds. Distributed simulation requires a novel approach to exercise management. Traditionally, exercise management of single-site simulations consists of managing a single simulator. With the introduction of (geographically) distributed simulations, exercise management consists of managing a multitude of simulators. This imposes new challenges with respect to managing the distributed responsibilities of the simulation.

SmartFED has been successfully used as an indispensable core element in several programs since its inception in 1996. A more detailed insight into the concepts of SmartFED and the practical experiences with SmartFED in the field of distributed real-time (training) simulations is given in the remainder of this paper. First however the concepts of exercise management will be discussed.

3 Exercise Management: The Concepts

Exercise management, for both single-site and distributed simulations, can be split into four distinct functionalities grouped into two major responsibilities:

1. Simulation execution state management
   a. Monitor the execution state
   b. Control the execution state
2. Simulation scenario management
   a. Monitor the simulation objects
   b. Control the simulation objects

Whilst both single-site and distributed simulation exercise management comprise the same functionalities, exercise management for distributed simulations is decisively more complex than for single-site simulations.

Whereas a single-site simulation usually has a well-defined execution state, the concept of execution state of a distributed simulation cannot be uniquely defined. Depending on the simulation exercise at hand the concept of execution state can be very strictly or more loosely

defined. For example, when deploying legacy single-site simulators in a distributed simulation exercise, a very strict definition of state could very well be unfeasible, so that the application of a more loosely defined execution state is necessary.

As is the case for state of execution, also scenario management of distributed simulations is more complex when compared to single-site simulations. Simulation objects in a distributed simulation can be controlled by two different concepts:

1. Request driven concept, where the scenario manager requests state changes of simulation objects from their controlling simulator.
2. Active control concept, where responsibility of simulation object attributes is transferred to the scenario manager. The scenario manager then has unrestricted direct control over those attributes.

Of course a mixture of these concepts is necessary, especially since federates may need special safety-measures, e.g. the safety of a pilot in a full motion flight simulator. The choice of which concept is used thus depends on the federates involved in the federation. Especially legacy simulators impose limitations on the amount of external influence that can be exercised on the simulation objects under their control.

4 SmartFED Supported Distributed Exercise Management

A typical distributed exercise management situation utilising SmartFED is depicted in Figure 2. In this case two human entities are identified, which together collaborate to perform exercise management. Whereas the supervisor controls the progress of the simulation execution, the trainer controls the content of the simulation execution.

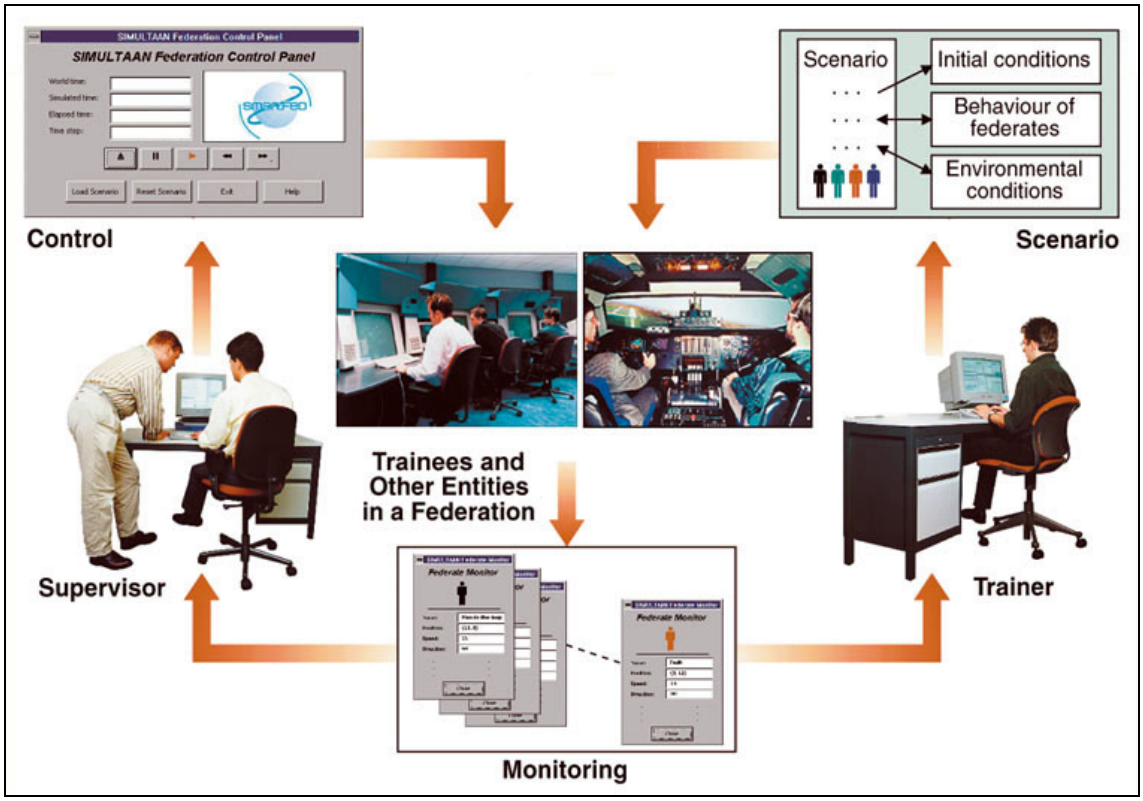


Figure 2: Typical (simplified) distributed exercise management situation involving aerospace federates.

SmartFED is a generic reusable tool-suite that provides support to the human exercise manager(s) controlling a real-time distributed simulation execution. At present the tool-suite encompasses three tools:

1. Federation Manager (FedMan): this tool implements support for simulation execution state management. It encompasses both monitor as well as control functionalities.
2. Federation Monitor (FedMon): this tool implements support to monitor simulation objects. It is remarked that more than one instantiation of FedMon is possible in a federation.
3. Scenario Definition and Execution Manager (SDEMan): this tool implements support to control simulation objects by means of both repeatable and interactive scenarios.

Some of the important properties of SmartFED are:

- HLA compliancy. SmartFED is a tool-suite where each of the tools operates as an HLA compliant federate. Although SmartFED has been designed to be fully HLA compliant, it has also been successfully ported to use a custom intercommunication protocol based on CORBA.
- Simulation scenario management support. Within SmartFED this support has been separated into two tools (i.e. FedMon and SDEMan) to facilitate multi-site monitoring, whilst preventing conflicts due to multiple controlling entities.
- Control concept. Currently SmartFED supports the request driven concept. A future version of SmartFED will also support the active control concept.
- FEDEP support. SmartFED supports the Integrate and Test Federation and the Execute Federation and Prepare Results steps (5 and 6 respectively) of the FEDEP model. The FEDEP support of SmartFED will be further discussed in Section 8.

5 Federation Manager

The SmartFED Federation Manager (FedMan) provides central control over the distributed real-time simulation. The human supervisor (see also Figure 2) operates the Federation Manager from any one of the participating sites.

FedMan has the ability to monitor the execution state of each of the participating federates. This enables the supervisor to take informed decisions on his control strategy and to monitor the effects of his actions. FedMan supports control of federation execution state by means of a general state transition diagram (STD), which is depicted in Figure 3.

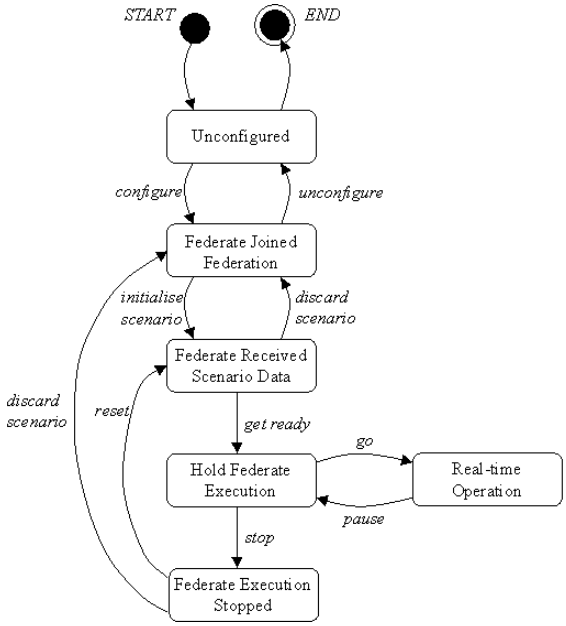


Figure 3: Federation state-transition diagram.

It is important to note that SmartFED does not impose any restrictions on a federate's internal STD. Federates may well possess an internal STD that differs from the one depicted in Figure 3. The main issue is that from an exercise management point of view, a federate complies with the depicted STD. FedMan sends state-transition commands to all federates. If applicable with regard to the selected control mode, federates reply with success or failure notifications.

During federation development it may appear that federates cannot comply with a federation STD since federates may have their own internal STD. Especially legacy simulators are made HLA compliant by building an HLA data gateway, which does not support external influence on flow of control. To deal with federations that utilise these kind of federates; FedMan supports two modes of control.

A strict control mode is available that enforces all federates to transfer into a requested state before the supervisor can forward execution to a next state. The second mode of control is a free-running mode that doesn't enforce federation wide state synchronisation. An example of a federation executing in free-running mode is depicted in Figure 4; note that different states are indicated for participating federates. The mode of control is selected at start-up of a federation and cannot be changed during federation execution.

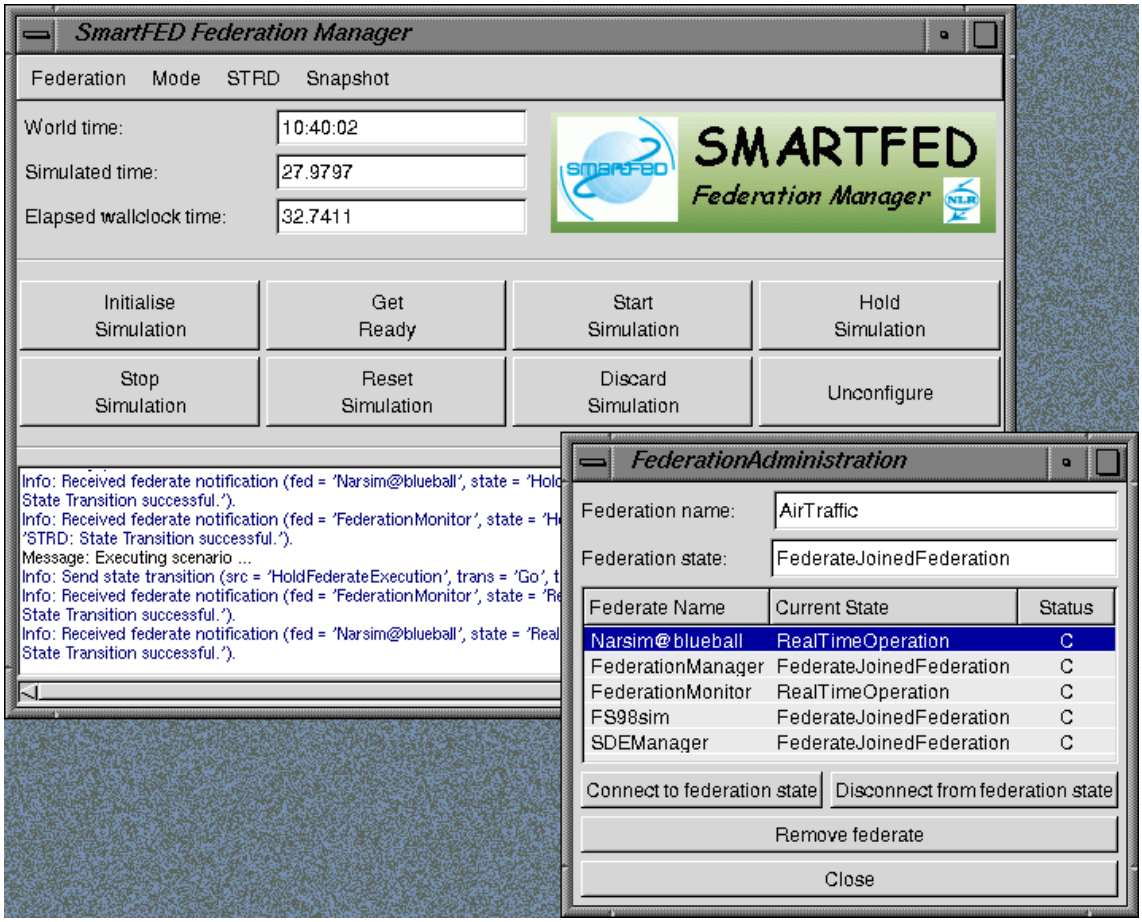


Figure 4: SmartFED Federation Manager.

For monitoring purposes FedMan provides a dedicated message window to notify the supervisor of warnings or errors that occur during the federation execution, for instance when a federate does not comply with a state transition request.

The Federation Manager supports the initiation of snapshots by sending a snapshot requests to the participating federates. A snapshot usually contains a dump of the entire internal state of a federate. Of course this is only possible as far as a federate supports snapshots. In order to preserve the real-time nature of the simulation, snapshots can be generated only when a federate is in the ‘Hold Federate Execution’ state.

6 The Federation Monitor

The SmartFED Federation Monitor (FedMon) provides information about simulation objects within an entire federation. The supervisor and the trainer (roles identified in Figure 2) both take advantage of the FedMon monitoring facilities, though they are by no means the only possible beneficiaries of the use of FedMon. FedMon can be instantiated as many times and on any location as is deemed beneficial. An example screenshot of several of these monitoring facilities and their display formats is depicted in Figure 5.

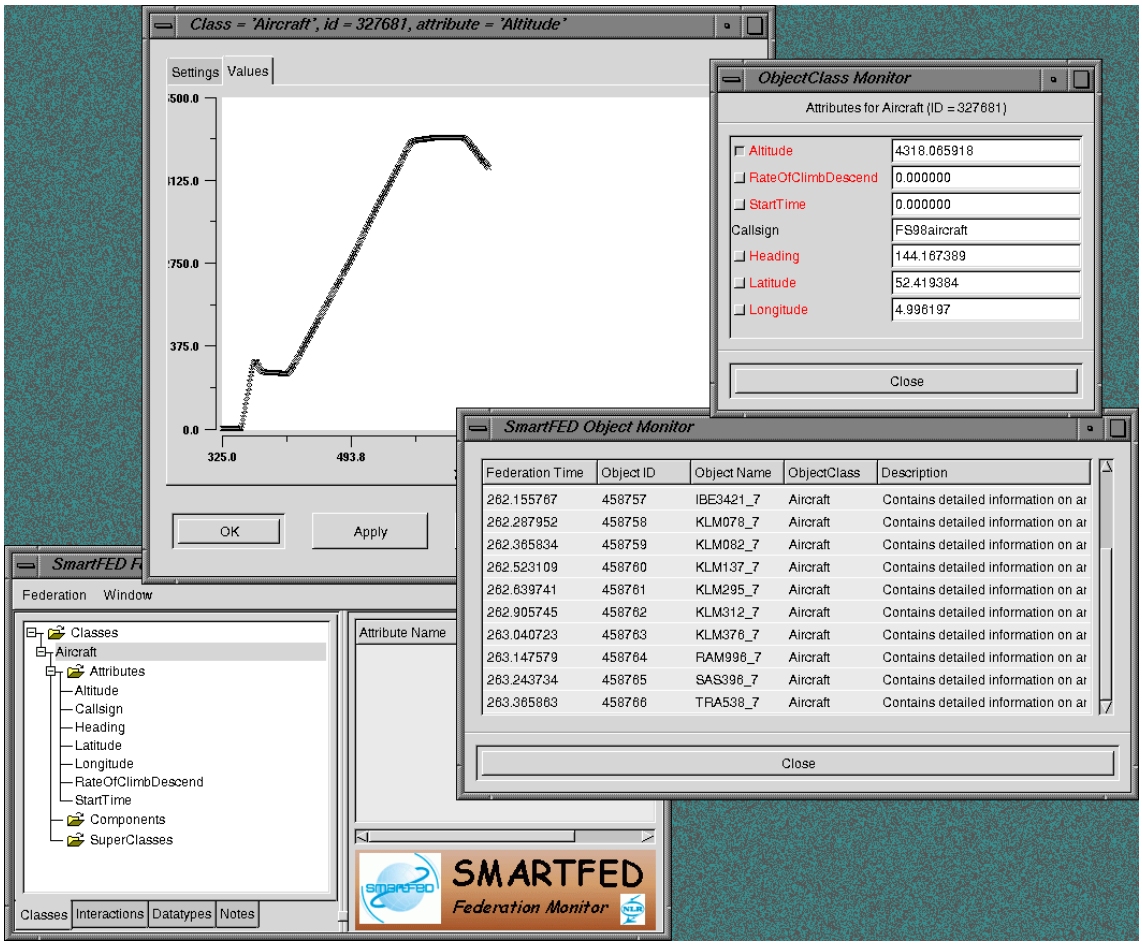


Figure 5: SmartFED Federation Monitor.

In HLA parlance, a simulation object can be either an instantiation of an object class or an instantiation of an interaction class. The difference is principally that an object has a significant lifetime, whilst an interaction takes place at a moment in time after which the interaction seizes to exist. HLA provides a standardised means to describe object and interaction classes that exist within a federation. For each federate a Simulation Object Model (SOM) must be defined. The SOM defines object and interaction classes that can be published or subscribed by that federate.

Federation wide, a Federation Object Model (FOM) must be defined. The FOM describes object and interaction classes from a federation point of view.

FedMon uses the FOM to structure access to all information available within the federation. A graphical representation of the FOM enables users to subscribe to information of their interest. FedMon provides both textual as well as graphical facilities to represent information about the federation and its simulation objects. Information monitoring can be categorised in three abstraction levels:

1. Simulation object/interaction class level. An overview can be displayed of all simulation objects in the federation of an indicated class.
2. Simulation object/interaction level. This level is supported by:
    a. a so-called Planview oversight. This monitoring facility is aimed at providing a 2D-overview of simulation objects that possess a simulated geographic location on earth, in the air or in space.
    b. an overview of all attribute/parameter values. The attributes/parameters are represented by the textual values.
3. Simulation object attribute/interaction parameter level. The user has the capability to configure views for specific attributes. For example, it is possible to view an attribute change over time.

7 The Scenario Definition and Execution Manager

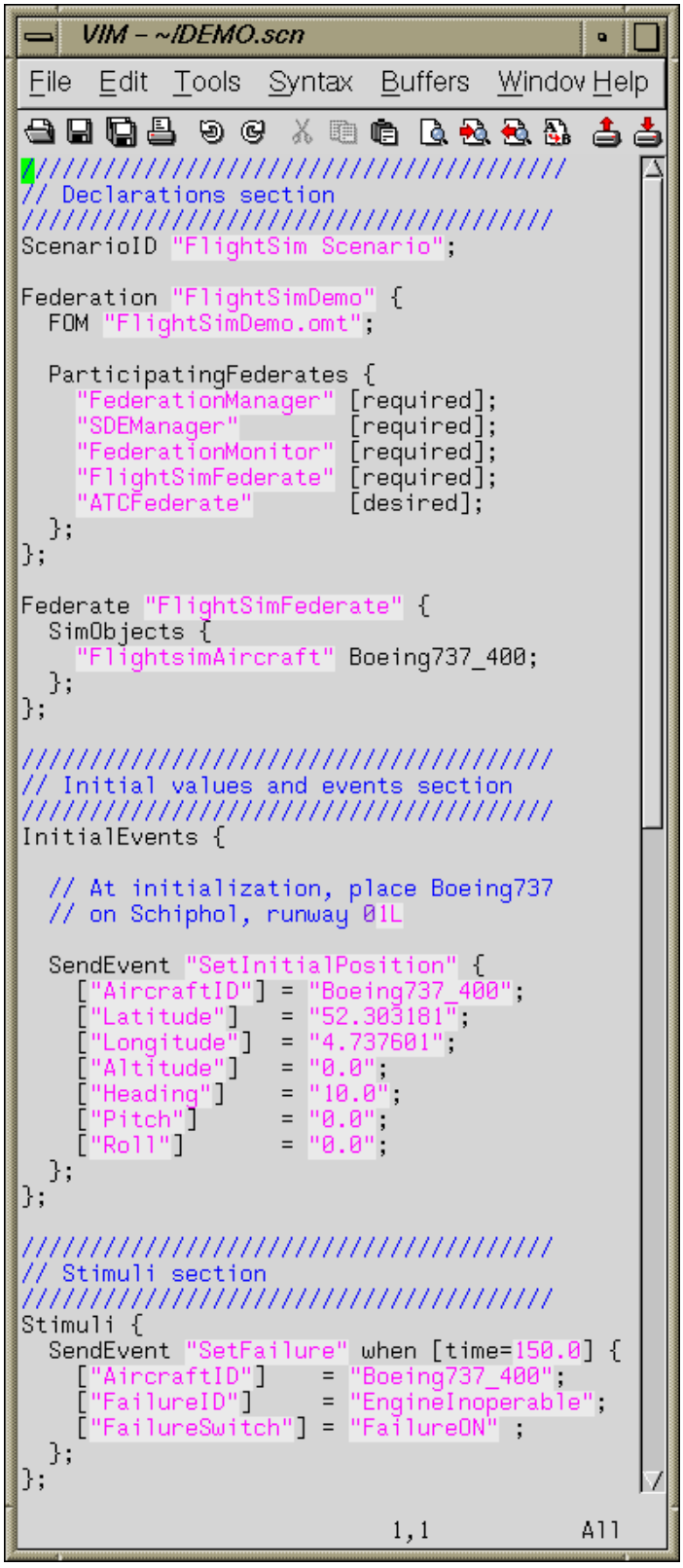
The Scenario Definition and Execution Manager obviously has two main tasks: scenario definition and scenario execution. The Scenario Definition component enables the user (e.g. the trainer in Figure 2) to specify a scenario prior to simulation execution. A scenario consists of the following parts; an example is depicted in Figure 6:

- Federation composition: defines the federation name and defines which federates in the federation participate in the specific scenario;
- Initial condition definition for each federate: the initial values of the federates data attributes (e.g. an aircraft position, speed);
- Stimuli definition during scenario execution: which events must occur at what time during the scenario.

SDEMan reads the predefined scenario file and sends all initial events to the federation when the Federation Manager generates the ‘initialise scenario’ command (see Figure 4). During the ‘Real-time Operation’ state (see Figure 3) the Scenario Execution component will send events to the federation at the times specified in the scenario.

The scenario definition capability gives exercise management the possibility to (re-)play predefined training exercises. However, during exercise execution it may often be necessary to provide the trainee(s) with ad-hoc generated events. Examples are the generation of failures or the generation of additional (friend and foe) objects.

The SmartFED scenario execution manager supports this capability by allowing the exercise manager to generate in principle all events that are defined in the FOM. In this way the scenario execution manager is more or less “symmetric” to the federation monitor: the monitor allows subscribe/unsubscribe actions with respect to the FOM classes and events, while the scenario execution manager allows publish actions.




```
////////////////////////////////////////
// Declarations section
////////////////////////////////////////
ScenarioID "FlightSim Scenario";

Federation "FlightSimDemo" {
  FOM "FlightSimDemo.omt";

  ParticipatingFederates {
    "FederationManager" [required];
    "SDEManager"        [required];
    "FederationMonitor" [required];
    "FlightSimFederate" [required];
    "ATCFederate"       [desired];
  };
};

Federate "FlightSimFederate" {
  SimObjects {
    "FlightsimAircraft" Boeing737_400;
  };
};

////////////////////////////////////////
// Initial values and events section
////////////////////////////////////////
InitialEvents {

  // At initialization, place Boeing737
  // on Schiphol, runway 01L

  SendEvent "SetInitialPosition" {
    ["AircraftID"] = "Boeing737_400";
    ["Latitude"]   = "52.303181";
    ["Longitude"]  = "4.737601";
    ["Altitude"]   = "0.0";
    ["Heading"]    = "10.0";
    ["Pitch"]      = "0.0";
    ["Roll"]       = "0.0";
  };
};

////////////////////////////////////////
// Stimuli section
////////////////////////////////////////
Stimuli {
  SendEvent "SetFailure" when [time=150.0] {
    ["AircraftID"]    = "Boeing737_400";
    ["FailureID"]     = "EngineInoperable";
    ["FailureSwitch"] = "FailureON" ;
  };
};
```

Figure 6: SmartFED Scenario file example.

8 FEDEP Support

The HLA Federation Execution and Execution Process (FEDEP) model [7] describes a high-level framework for the development and execution of HLA federations. The intent of the FEDEP model is to specify a set of guidelines for federation development and execution that federation developers can use to achieve the needs of their application.

The FEDEP process is depicted in Figure 7. SmartFED supports the Integrate and Test Federation (step 5) and the Execute Federation and Prepare Results (step 6) steps of the FEDEP model with the following capabilities:

- Federate testing is supported to validate the various federates with respect to the FOM. By performing this kind of (stand-alone) validation before the federates are integrated into the overall federation (usually by a "big bang" integration) faults can be detected and repaired at an early stage, thereby saving time and reducing costs.
- Federation integration testing is supported where the integrated federation is tested to "verify a basic level of interoperability". Testing the state transition diagram of FedMan can easily test this basic level of interoperability.
- Validating the complete integrated federation against the FOM.
- Scenario instances (input to step 5) can be implemented by the scenario file mechanism of SDEMan as discussed in Section 7.
- SmartFED provides logging files to support after action reviews of federation execution.

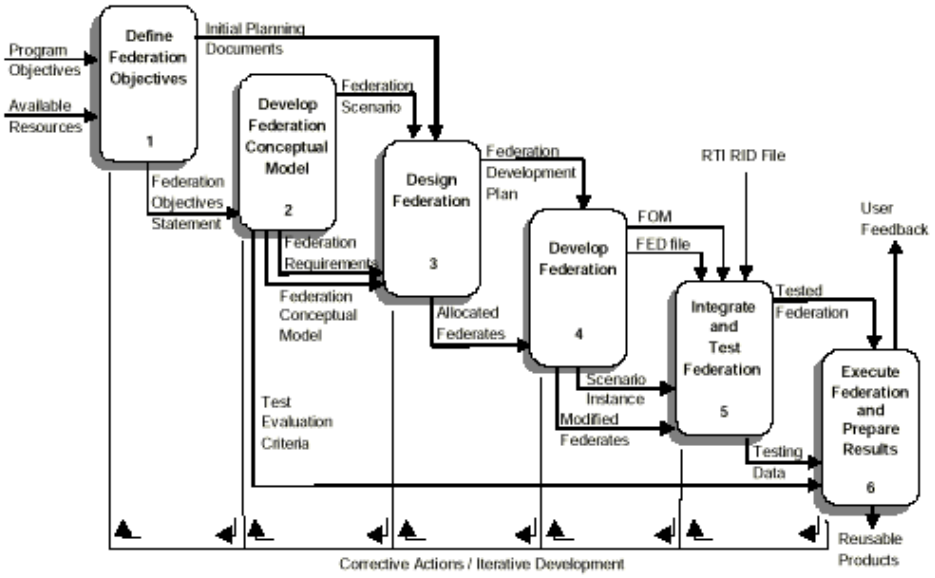


Figure 7: FEDEP's six-step model (from [7]).

9 Concluding remarks and future work

The growing interest in utilisation of distributed simulations has led to the development of a standardised intercommunication mechanism as well as a standardised process for federation development and execution. Exercise management has not been standardised yet. This has led to the development of the Scenario MAnager for Real-Time FEderation Directing (SmartFED) tool-suite, which provides tool support for distributed exercise management in real-time. The SmartFED tool-suite is successfully used in a number of aerospace projects.

SmartFED utilises the standardised intercommunication mechanism HLA and supports the standardised FEDEP process. Several practical applications utilise SmartFED from which experiences are gathered and used for product improvement. The generic STD deployed by the FedMan tool will be enhanced by the support for a user-defined federation execution STD. The current generic STD will still be available as a default instantiation of such a user-defined STD.

A limiting factor in world-wide simulation through connecting simulation facilities using for instance HLA is often the available bandwidth. The SmartFED tool-suite will be extended with a so-called Federation Timing tool (FEDTim) that can be used to perform specific measurements on data flows between federates in a federation.

The use of an automated tool to validate a federate/federation (as discussed in Section 8) may raise questions about the quality of the tool. To anticipate this, SmartFED is in the process of being qualified as verification tool in the sense of [8]. In [8], software verification tools are described as tools that cannot introduce errors, but may fail to detect them (this in contrast to development tools, that can introduce errors). SmartFED tool qualification now consists of demonstrating that “the tool complies with its Tool Operational Requirements under normal operational conditions”. Basically, this means that SmartFED is undergoing a stringent verification process, with several test federations.

10 References

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